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DEVICE TO CORRECT INTERFERENCE ERRORS BETWEEN MAGNETIC SENSORS
FOR MEASURING THE POSITION OF MOBILE ELEMENTS

This present invention concerns the technical area of contactless magnetic sensors designed to locate the position of a mobile element that is in motion along a movement axis, preferably linear.

5 The subject of the invention has a particularly advantageous application in the area of motor vehicles, though not exclusively so, with a view to equipping different moving devices, particularly in linear movement, whose position has to be known, and forming part, for example, of an automatic
10 gearbox, a suspension system, a transmission clutch, an assisted steering system, a seat regulating sensor, etc.

 In previous designs, there are many types of contactless sensor designed to ascertain the linear position of a mobile element that is moving in translation. For example, patent US
15 4 810 965 described a magnetic sensor that includes a closed magnetic circuit with a U-shaped polar part equipped, between its two free ends, with a magnet creating a magnetic field in a direction perpendicular to the surface of the polar part. A mobile measurement cell is mounted between the branches of the
20 polar part in order to measure the value of the magnetic field in relation to the surface area of the polar part. Such a cell thus measures the strength of the magnetic leakage field appearing between the two branches of the polar part, where the strength of this magnetic leakage field varies with the
25 surface area of the polar part along the axis of translation of the measuring cell. Such a sensor also includes resources for processing the output signal delivered by the measuring cell, in order to determine the linear position of the mobile element along the axis of translation.

In certain applications, such as a controlled clutch for example, a need arises to ascertain the linear position of mobile elements that are moving close to each other. The linear position of each mobile element can then be determined
5 using a magnetic measuring sensor as described above.

The Applicant was able to observe that the measurements effected by one magnetic sensor were disrupted by the other magnetic sensor. In other words, the Applicant observed interference errors in an installation that included at least
10 two magnetic sensors for measuring the position of mobile elements that are moving along adjacent trajectories.

The subject of the invention therefore aims to remedy the interference errors appearing in such a measuring installation. To this end, the subject of the invention aims
15 to propose a device to correct the interference errors for a measuring installation that includes:

- at least two magnetic sensors for measuring the position of mobile elements that are moving along adjacent trajectories, with each magnetic measuring sensor delivering a
20 measurement signal that is representative of the position of the mobile element in an open magnetic circuit,
- and resources for processing the measurement signals delivered by the magnetic measuring sensors.

According to the invention, the processing resources
25 include resources for correction of the magnetic measurement signals in order to take account of interference errors between adjacent magnetic sensors with a view to obtaining a corrected measurement signal for each magnetic measuring sensor.

30 Advantageously, the correction resources correct the measurement signal of each magnetic measuring sensor according to the value of the measurement signals of the magnetic

measuring sensor concerned and of the other magnetic measuring sensors.

According to one characteristic of the invention, the processing resources deliver a corrected measurement signal
5 for each magnetic measuring sensor such that:

$$S_{1c} = \sum_{i=1}^n \left(\sum_{j=0}^i \alpha_{ij} S_1^j S_2^{i-j} \right)$$

$$S_{2c} = \sum_{i=1}^n \left(\sum_{j=0}^i \alpha'_{ij} S_2^j S_1^{i-j} \right)$$

where : α and α' are correction coefficients and n is the order of the correction.

According to an implementation variant, the processing
10 resources deliver a corrected measurement signal for each magnetic measuring sensor, such that, for a correction order of $n = 3$, α , i , j and α' , are such that:

$$\begin{aligned} \alpha_{10} &= a - c, & \alpha_{11} &= 1 + c \\ \alpha'_{10} &= a' - c', & \alpha'_{11} &= 1 + c' \\ 15 \quad \alpha_{20} &= 0 = \alpha'_{20}, & \alpha_{21} &= \alpha'_{21} = 0, & \alpha_{22} &= \alpha'_{22} = 0 \\ \alpha_{30} &= -b, & \alpha_{31} &= 3b, & \alpha_{32} &= -3b, & \alpha_{33} &= b \\ \alpha'_{30} &= -b', & \alpha'_{31} &= 3b', & \alpha'_{32} &= -3b', & \alpha'_{33} &= b' \end{aligned}$$

where a , b , c , a' , b' and c' are correction coefficients so that:

$$\begin{aligned} 20 \quad S_{1c} &= (1 + c) S_1 + (a - c) S_2 + 3b S_1 S_2^2 - 3b S_1^2 S_2 + b S_1^3 - b S_2^3 \\ S_{2c} &= (1 + c') S_2 + (a' - c') S_1 + 3b' S_2 S_1^2 - 3b' S_2^2 S_1 + b' S_2^3 - b' S_1^3 \end{aligned}$$

or

$$S_{1c} = S_1 + a S_2 + b (S_1 - S_2)^3 + c (S_1 - S_2)$$

and

$$25 \quad S_{2c} = S_2 + a' S_1 + b' (S_2 - S_1)^3 + c' (S_2 - S_1)$$

According to another implementation variant, the processing resources deliver a corrected measurement signal for each magnetic measuring sensor such that, for a correction

order $n = 1$, the values of α , α' , i and j are such that $\alpha_{10} = a$, $\alpha_{11} = 1$ and $\alpha'_{10} = a'$, $\alpha'_{11} = 1$ so that:

$$S_{1c} = S_1 + aS_2, \text{ and } S_{2c} = S_2 + a'S_1$$

Advantageously, each measurement signal S_1 , S_2 is such that:

$$S_1 = \frac{S_a - S_b}{S_a + S_b}$$

$$S_2 = \frac{S_d - S_c}{S_d + S_c}$$

where S_a , S_b , and S_c , S_d are a pair of elementary measurement signals delivered by a pair of measurement cells mounted in the open magnetic circuit.

Another aim of the invention is to propose a measuring installation that includes:

- a first magnetic measuring sensor delivering a first signal for measuring the position of a first mobile element that is moving along a trajectory, where the value of the first measurement signal depends on the position of the said mobile element in an open magnetic circuit,
- at least one second magnetic measuring sensor delivering a second magnetic signal for measuring the position of a second mobile element that is moving along a trajectory adjacent to trajectory of the first mobile element, where the value of the second measurement signal depends on the position of the said mobile element in an open magnetic circuit,
- and a correction arrangement according to the invention.

Another aim of the invention is to propose a contactless magnetic sensor designed to determine the position of a mobile element, being of simple, economic design and capable of operating with a wide magnetic gap.

Thus each magnetic measuring sensor of the installation according to the invention includes resources for the creation of a magnetic flux in a direction perpendicular to the surface

of at least one polar part, from which there emanates a magnetic leakage flux whose magnitude varies with the surface area of the polar part along the axis of movement, where these magnetic flux creation resources are mounted to be movable by the mobile element to form at least one magnetic gap with a polar part forming part of the open magnetic circuit, with each magnetic measuring sensor including at least one measuring cell mounted in a fixed manner in the magnetic circuit, close to an end point of the trajectory so as to measure the magnetic flux delivered by the creation resources less a magnetic leakage flux emanating from the polar part and varying along the trajectory.

For example, the magnetic flux creation resources of the two measuring sensors are mounted close to each other along parallel trajectories.

According to a preferred implementation variant, the magnetic sensor includes a second measuring cell mounted in a fixed manner in the magnetic circuit close to the other trajectory end point so as to measure the magnetic flux delivered by the creation resources less the magnetic leakage flux.

Advantageously, the magnetic flux creation resources are mounted to be movable in translation.

Advantageously, the magnetic flux creation resources are composed of a disk-shaped or annular element, magnetised radially or axially, and whose axis is parallel to the translation axis.

According to another form of implementation, the magnetic flux creation resources are composed of a series of at least four magnets whose directions of magnetisation are shifted, two by two, by 90° .

According to another form of implementation, the magnetic flux creation resources are composed of at least one magnet

of at least one polar part, from which there emanates a magnetic leakage flux whose magnitude varies with the surface area of the polar part along the axis of movement, where these magnetic flux creation resources are mounted to be movable by the mobile element to form at least one magnetic gap with a polar part forming part of the open magnetic circuit, with each magnetic measuring sensor including at least one measuring cell mounted in a fixed manner in the magnetic circuit, close to an end point of the trajectory so as to measure the magnetic flux delivered by the creation resources less a magnetic leakage flux emanating from the polar part and varying along the trajectory.

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whose direction of magnetisation is parallel to the translation axis.

According to certain applications, the open magnetic circuit includes a second polar part placed opposite to the first polar part, creating a magnetic gap with the latter.
According to this implementation variant, the second polar part is equipped with the magnetic flux creation resources.

For example, this second polar part is formed from a tubular element fitted with the radially magnetised annular element.

Advantageously, one or other of the polar parts has a plane profile designed to improve the linearity of the output signal delivered by the measurement cells.

Diverse other characteristics will emerge from the description provided below with reference to the appended drawings which show, by way of non-limiting examples, some forms of implementation of the subject of the invention.

- Figure 1 is a diagrammatic view of a measuring installation that implements a correction arrangement according to the invention.

- Figures 2 and 3 are graphs illustrating an aspect of the invention.

- Figure 4 is a diagrammatic view showing the principle of a sensor implemented within the scope of the invention.

- Figure 5 is a diagrammatic view in perspective showing a preferred implementation variant of the sensor used.

- Figures 6 and 7 are views in perspective showing diverse forms of implementation of the magnetic flux creation resources.

- Figures 8 and 9 illustrate two outline implementation variants of polar parts capable of being implemented by a sensor within the scope of the invention.

- Figures 10 and 11 are views in perspective of two implementation variants of the sensor within the scope of the invention.

As shown in greater detail in figure 1, the subject of the invention concerns a device to correct interference errors in a measuring installation A that includes at least two magnetic sensors 1_1 , 1_2 , each designed to measure the position of a mobile element, respectively 2_1 , 2_2 , which are moving along adjacent trajectories. Each magnetic sensor 1_1 , 1_2 includes an open magnetic circuit 3_1 , 3_2 and delivers a measurement signal which is representative of the position of the mobile element 2_1 , 2_2 in the said open magnetic circuit. This measuring installation A also includes resources M for processing the measurement signals S_1 , S_2 delivered respectively by the magnetic sensors 1_1 , 1_2 .

According to the invention, the processing resources M include resources for correction of the magnetic measurement signals S_1 , S_2 in order to take account of interference errors between the adjacent magnetic sensors 1_1 , 1_2 , with a view to obtaining a corrected measurement signal S_{1c} , S_{2c} for each magnetic measuring sensor. In fact, it has been observed that the measurements performed by a sensor are disrupted by the presence of the other sensor and vice versa. The subject of the invention therefore aims to correct the magnetic measurement signals S_1 , S_2 in order to take account of the interference between the sensors.

According to an advantageous implementation characteristic, the correction resources correct the measurement signal S_1 , S_2 of each magnetic measuring sensor according to the value of the measurement signals of the magnetic measuring sensor concerned and of the other magnetic measuring sensors. In fact, it has been observed that the magnitude of the disruption created by a sensor is dependent

upon the value taken by the said sensor and the value taken by the other sensor. Thus, for example, in the case of measurements of the linear position of two adjacent mobile elements, the measurement read by sensor 1_1 is disrupted by the presence of mobile element 2_2 with which sensor 1_2 is associated. This disruption is dependent upon the position of mobile element 2_2 . Furthermore, for a given position of mobile element 2_2 , the disruption is also dependent upon the position of mobile element 2_1 . Conversely, the measurement read by sensor 1_2 is disrupted by the presence of mobile element 2_1 , with which sensor 1_1 is associated. This disruption is dependent upon the given position of mobile element 2_1 . Also, for a given position of mobile element 2_1 , the disruption is also dependent upon the position of mobile element 2_2 .

For a measuring installation A, it is possible to determine the error in measurement signal S_1 as a function of measurement signal S_2 . The graph of figure 2 represents this error Δ on measurement signal S_1 as a function of measurement signal S_2 . It emerges from this graph that the error ΔS_1 is globally a linear function of measurement signal S_2 . It is thus possible, knowing measurement signals S_1 and S_2 , to specify a corrected measurement signal for sensor 1_1 such that $S_{1c} = S_1 + aS_2$.

Likewise, it is possible to specify a corrected measurement signal for sensor 1_2 , such that $S_{2c} = S_2 + a'S_1$, where a and a' are correction coefficients.

It should be noted that such a corrected signal S_{1c} , S_{2c} remains affected by errors because of the linear approximation of the correction made (correction of order $n = 1$).

The residual error δ after this correction of order 1 is shown in figure 3, as a function of the difference between signals $S_1 - S_2$. This residual error can, for example, be approximated by a polynomial of order 3 on $(S_1 - S_2)$, in which

the coefficients of the even exponents are zero. Thus, it is possible, for a correction order of order 3 ($n = 3$) to calculate a corrected signal such that:

$$S_{1c} = (1 + c)S_1 + (a - c)S_2 + 3bS_1S_2^2 - 3bS_1^2S_2 + bS_1^3 - bS_2^3$$

5 and

$$S_{2c} = (1 + c')S_2 + (a' - c')S_1 + 3b'S_2S_1^2 - 3b'S_2^2S_1 + b'S_2^3 - b'S_1^3$$

or

$$S_{1c} = S_1 + aS_2 + b(S_1 - S_2)^3 + c(S_1 - S_2)$$

and

$$10 \quad S_{2c} = S_2 + a'S_1 + b'(S_1 - S_2)^3 + c'(S_2 - S_1)$$

where b , c , b' , and c' are correction coefficients.

In general, it is possible to specify a corrected measurement signal for each measuring sensor such that:

$$S_{1c} = \sum_{i=1}^n \left(\sum_{j=0}^i \alpha_{ij} S_1^j S_2^{i-j} \right)$$

$$S_{2c} = \sum_{i=1}^n \left(\sum_{j=0}^i \alpha'_{ij} S_2^j S_1^{i-j} \right)$$

15 where α and α' are correction coefficients and n is the correction order.

For a correction order of order 3 ($n = 3$), α , i , j and α' are such that:

$$\alpha_{10} = a - c, \quad \alpha_{11} = 1 + c$$

$$20 \quad \alpha'_{10} = a' - c', \quad \alpha'_{11} = 1 + c'$$

$$\alpha_{20} = 0 = \alpha'_{20}, \quad \alpha_{21} = \alpha'_{21} = 0, \quad \alpha_{22} = \alpha'_{22} = 0$$

$$\alpha_{30} = -b, \quad \alpha_{31} = 3b, \quad \alpha_{32} = -3b, \quad \alpha_{33} = b$$

$$\alpha'_{30} = -b', \quad \alpha'_{31} = 3b', \quad \alpha'_{32} = -3b', \quad \alpha'_{33} = b'$$

so that

$$25 \quad S_{1c} = (1 + c)S_1 + (a - c)S_2 + 3bS_1S_2^2 - 3bS_1^2S_2 + bS_1^3 - bS_2^3$$

$$S_{2c} = (1 + c')S_2 + (a' - c')S_1 + 3b'S_2S_1^2 - 3b'S_2^2S_1 + b'S_2^3 - b'S_1^3$$

or

$$S_{1c} = S_1 + aS_2 + b(S_1 - S_2)^3 + c(S_1 - S_2)$$

and

$$S_{2c} = S_2 + a'S_1 + b'(S_2 - S_1)^3 + c'(S_2 - S_1)$$

For a correction order of 1, the values of α , i , j and α' are such that:

5 $\alpha_{10} = a, \alpha_{11} = 1, \alpha'_{10} = a', \text{ and } a'_{11} = 1$

It emerges from the above description that the resources for processing the signals enable one to correct the interference errors in a measuring installation A that includes two magnetic sensors for measuring the position of
10 mobile elements $2_1, 2_2$ that are moving close to each other. Of course the subject of the invention can be applied equally well to a measuring installation A that includes more than two magnetic measuring sensors.

Each magnetic sensor $1_1, 1_2$ can be implemented in any
15 known manner in order to measure the position of a mobile element that is moving along a given trajectory. Figure 4 shows a preferred implementation example of a magnetic sensor 1_1 designed to determine the position of a mobile element 2_1 in the general sense, travelling along a movement axis T_1 which,
20 in the example illustrated, is a translation axis. The mobile element 2_1 is composed of any type of device having, in the example illustrated, a linear course forming part, preferably though not exclusively, of a device fitted to a motor vehicle. In the remainder of the description, the mobile element 2_1 is
25 considered to have a linear course, though it is clear that the subject of the invention can apply to a mobile element 2_1 having a different course of movement, such as a circular one. In general, the mobile element 2_1 moves along the movement axis T_1 between two end points, denoted P_1 and P_2 in the
30 example illustrated in figure 4.

The sensor 1_1 includes a fixed magnetic circuit 3_1 that includes resources 4_1 for the creation of a magnetic flux which, in the example illustrated, is oriented in a direction

f_1 perpendicular to the translation axis T_1 . The magnetic circuit 3_1 also includes at least one first polar part 5_1 having a surface 6_1 that lies more or less perpendicularly to the direction f_1 of the magnetic flux and parallel to the translation axis T_1 .

The resources 4_1 for the creation of the magnetic flux are mounted to be movable by the mobile element 2_1 creating a magnetic gap 8_1 with the first polar part 5_1 . The magnetic flux creation resources 4_1 are preferably composed of a magnet forming part, or assembled in any appropriate manner to the mobile element 2_1 whose position will be determined along the movement axis T_1 . The magnet 4_1 thus delivers a magnetic flux that is oriented perpendicularly to the surface 6_1 of the first polar part 5_1 . It should be noted that it is possible to obtain a magnetic flux oriented perpendicularly to the surface 6_1 of the first polar part 5_1 with a magnet whose direction of magnetisation is parallel to the translation axis.

It should be considered that the polar part 5_1 has a length that is least equal to the course to be measured of the mobile element 2_1 , determined between the end points P_1 and P_2 . Apart from this, as will be seen from the description that follows, the first polar part 5_1 is made from a material that is chosen to limit the hysteresis effect, and with the appropriate dimensions to prevent reaching its magnetic saturation value.

The sensor 1_1 includes at least one first measuring cell 11_1 , mounted in the magnetic circuit 3_1 and able to measure the value of the magnetic flux in relation to the first polar part 5_1 . Such a measuring cell 11_1 , like a Hall-Effect cell for example, is able, at a given fixed position, to measure variations in the value of the magnetic flux flowing in the magnetic circuit. In the example illustrated in figure 4, the measuring cell 11_1 is mounted close to a movement end point P_2 .

More precisely the measuring cell 11_1 is mounted outside the course of the mobile element 2_1 and close to a movement end point.

It should be understood that the cell 11_1 measures the magnetic flux delivered by the magnet 4_1 less the magnetic leakage flux of which some field lines F are shown in figure 4. The cell 11_1 thus measures the residual magnetic flux at one end of movement, this residual magnetic flux being equal to the total flux of the magnet 4_1 less the direct magnetic leakage flux between the magnetic circuit 3_1 and the magnet 4_1 . In the measurements where the leakage flux is dependent, in a monotone manner, on the relative positions of the magnet 4_1 and the cell 11_1 , the output signal delivered by the cell 11_1 provides information on the position of the magnet 4_1 , and therefore of the mobile element 2_1 along the translation axis T_1 . Of course, this measurement is possible if the magnetic circuit, and in particular the polar part 5_1 , is not saturated. The output signal delivered by the measuring cell 11_1 is transmitted to signal processing resources, such as those described above, and used to determine the linear position of the mobile element 2_1 along the movement axis T_1 .

According to a preferred implementation characteristic, the sensor 1_1 includes a second measuring cell 13_1 , mounted in a fixed manner in the magnetic circuit 3_1 close to the other end point, namely P_1 , in the example illustrated in figure 5. As explained above, the cells 11_1 and 13_1 , are placed outside the course shown between points P_1 and P_2 . This second measuring cell 13_1 is also able to measure the magnetic flux delivered by the magnet 4_1 less the magnetic leakage flux. It should be noted that in the examples illustrated, the measurement cells 11_1 and 13_1 are fixed to the polar part 5_1 . Of course, the measurement cells 11_1 , 13_1 can be placed close

to the end points P_1 and P_2 without being in direct contact with the polar part 5_1 .

The creation of a magnetic sensor 1_1 that has two measurement cells 11_1 , 13_1 allows one to obtain a differential measurement structure with a view to improving the linearity of the output signal S_a , S_b of the measurement cells.

According to one implementation characteristic, one can envisage that, in order to determine the position of the mobile element 2_1 , the processing resources calculate the difference between the output signals S_a , S_b delivered by the first 11_1 and the second 13_1 measurement cells, divided by the sum of the output signals delivered by the first 11_1 and the second 13_1 measurement cells. Therefore $S_1 = (S_a - S_b) / (S_a + S_b)$, where S_a and S_b are the elementary measurement signals delivered by the pair of measurement cells 11_1 , 13_1 . Such a process allows one to obtain an output signal which is not very sensitive to variations in the signals delivered by the cells 11_1 , 13_1 due, for example, to variations in the magnetic gap or the temperature.

In the example illustrated in figures 4 and 5, the magnetic flux creation resources 4_1 are implemented by means of a magnet whose direction of magnetisation is perpendicular to the surface 6_1 of the first polar part 5_1 . In the case where the mobile element 2_1 also undergoes a rotation along the axis T_1 , it is possible to envisage, as illustrated in figure 6, creating the magnetic flux creation resources 4_1 by means of an annular element 14_1 or in the form of a radially magnetised disk whose axis A_1 is parallel to the movement axis T_1 . In the example illustrated in figure 7, the resources 4_1 for creation of the magnetic flux are composed of a series of at least four magnets 15_1 whose directions of magnetisation are shifted, two by two, by 90° .

According to an advantageous characteristic illustrated more precisely in figures 8 and 9, the polar part 5_1 can have a plane profile designed to improve the linearity of the output signal delivered by the measurement cells 11_1 , 13_1 . As
 5 an example, the polar part 5_1 can have a symmetrical area formed by two truncated cones mounted end to end with their wider bases joined (figure 8) or with their small bases joined (figure 9).

Figure 10 illustrates another implementation variant of
 10 the sensor implementing a second polar part 18_1 that can be identical or not to the first polar part 5_1 , and used to limit the magnetic leakage, meaning that it is used to channel the magnetic flux in the magnetic circuit 3_1 . In the example illustrated in figure 10, the second polar part 18_1 includes a
 15 plane surface placed opposite to the first polar part 5_1 forming, together with the latter, a magnetic gap 19_1 at one of its ends. The other end of this second polar part 18_1 is equipped with a magnet 4_1 which also forms a small magnetic gap 8_1 with the first polar part 5_1 .

20 Figure 11 illustrates another form of implementation of the second polar part 18_1 , created with a tubular element on which the radially magnetised annular element 14_1 is mounted as illustrated in figure 6. This second polar part 18_1 also forms a magnetic gap 19_1 with the first polar part 5_1 .

25 In the preceding description, only sensor 1_1 was described precisely. Of course, the second sensor 1_2 , which can be created in the same way as sensor 1_1 , will not be described in greater detail, to the extent that it has the same component elements but with the index 2 instead of the
 30 index 1. The second sensor 1_2 thus delivers two elementary measurement signals S_c , S_d .

The invention is not limited to the examples described and illustrated, since diverse modifications can be made to it without moving outside of its scope.